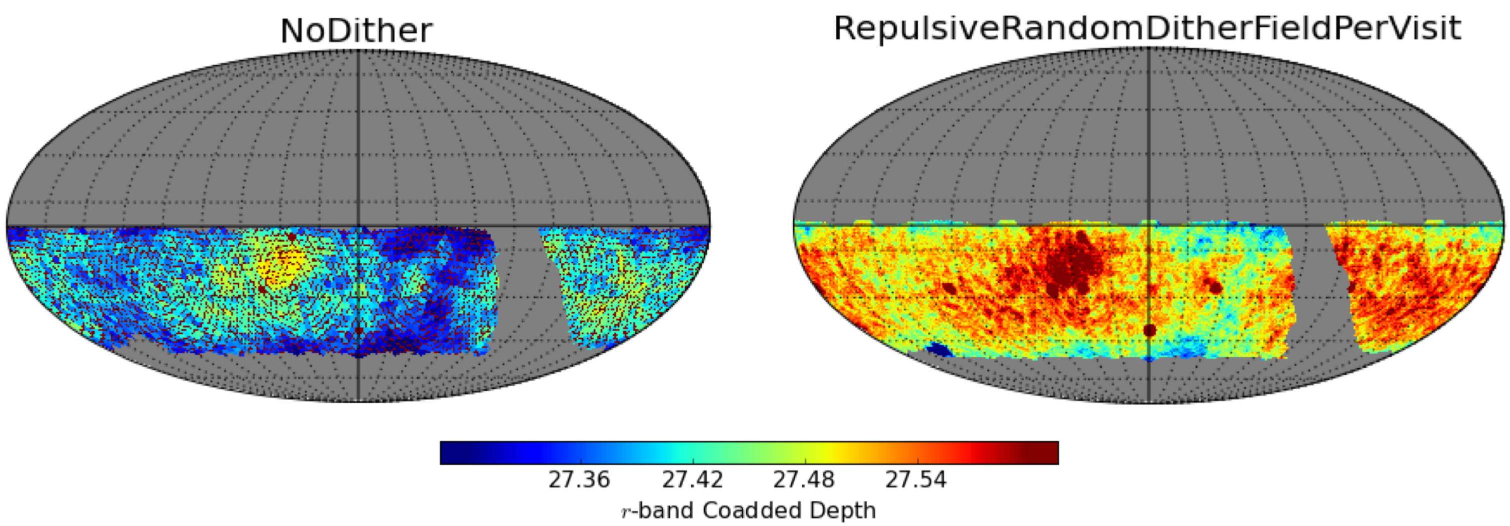
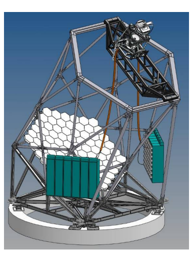
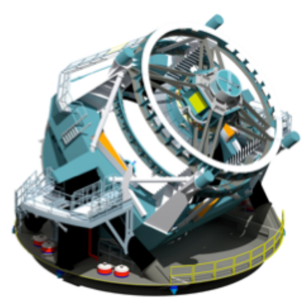
Dazed & Confused: Multi-wavelength Coverage of the LSST Deep Fields +LSST Survey Strategy +HETDEX





Eric Gawiser
Rutgers University



Official Motto of This Meeting

"Cross-correlate everything"

(thanks to Rachel Mandelbaum)

LSST Deep Drilling Fields (DDFs): Motivation

Take this unprecedented imager and go as deep as possible in single pointings

Can go 2 magnitudes (6X) deeper than LSST main survey over 10 □° in 1% of total LSST survey time

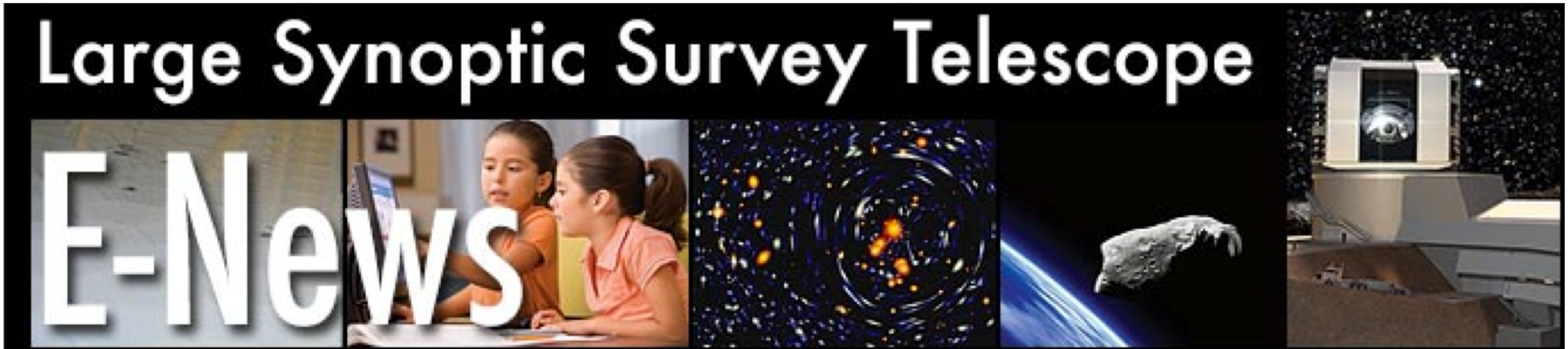
vs. HUDF: 5000X more area, 1 mag shallower

Need to avoid confusion limit in g r i (or use space-based image to resolve)

Systematics constraints by treating these fields as "truth" for e.g., photo-z & galaxy shapes

LSST DDF White Papers at
https://project.lsst.org/content/whitepapers32012

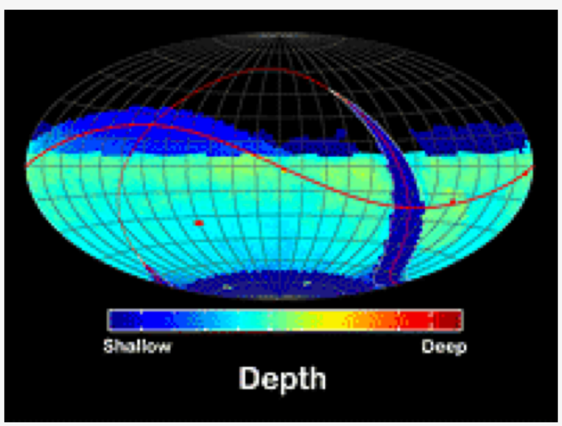
LSST Deep Fields: First 4 (of ~10)



LSST E-News

March 2012 • Volume 4 Number 4

Selection of Four Deep Drilling Fields for the LSST



LSST sky coverage map showing four Deep Drilling Fields.

	ELAIS S1	XMM-LSS	Extended Chandra Deep Field-South	COSMOS
RA 2000	00 37 48	02 22 50	03 32 30	10 00 24
DEC 2000	-44 00 00	-04 45 00	-28 06 00	+02 10 55
Galactic l	311.30	171.20	224.07	236.83
Galactic b	-72.90	-58.77	-54.47	42.09
Ecliptic l	345.97	31.04	40.29	150.70
Ecliptic b	-43.18	-17.90	-45.47	-9.39

LSST Deep Fields: Multiwavelength Coverage

3 / 4 announced DDFs are DES supernova deep fields

Spitzer Warm Mission (3.6, 4.5 micron) coverage of first 4 DDFs (Mark Lacy et al., 40 □°)

Deep near-IR imaging "easy" from space (WFIRST GO?)
Should coordinate with (some of) 40 □° of Euclid Deep Fields: see talk by Jason Rhodes

Deep wide-field spectroscopy feasible across 40-100 □°

Richest LSST regions for cross-correlation

LSST Survey Strategy: Motivation

Tremendous freedom in where to point LSST & when (and in which filter)

Cadence constrained by NEOs, SNe, many other transients

"Dithers" are telescope translations and camera rotations that can be performed each time LSST visits a given sky location

The LSST Operations Simulator

Non-trivial survey design task to cover
18,000 square degrees divided into
2000 pointings, each observed
~150 times in each of 6 filters.

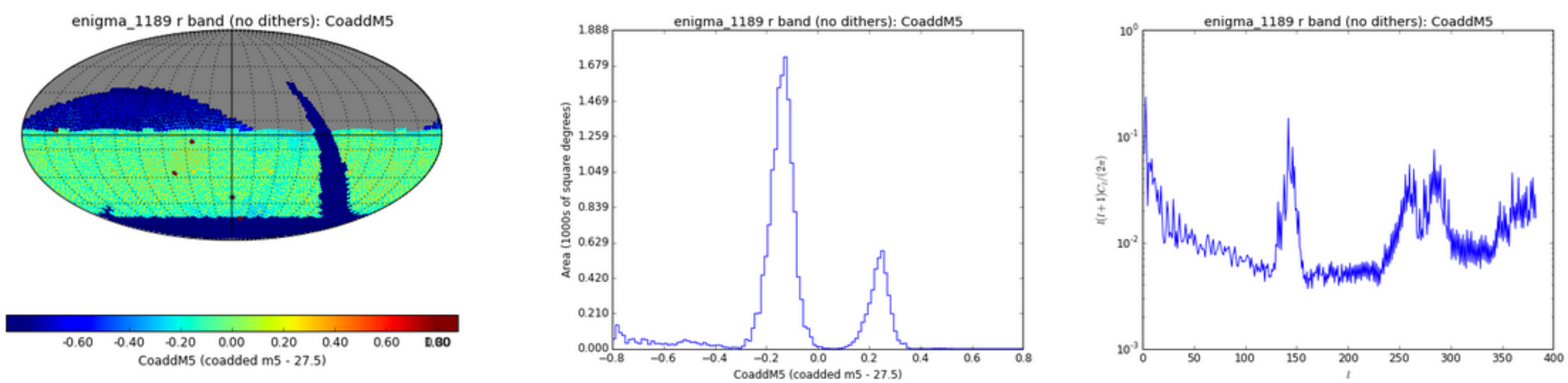
Feasibility shown via Operations Simulator (OpSim)

Metrics Analysis Framework (MAF)

OpSim Output:
Simulated pointing history
(MJD, RA, Dec, filter,
rotatorAngle, seeing, m5 ..)

MAF
Python framework
to calculate metrics

CoaddM5 HealpixSlicer r band (no dithers) [npz](npz) JSON

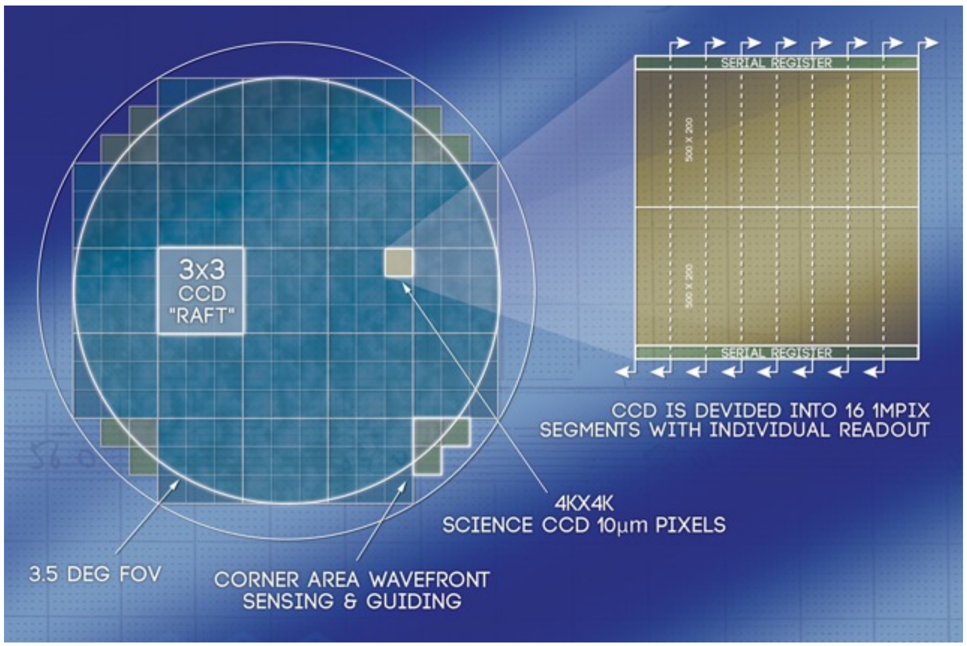


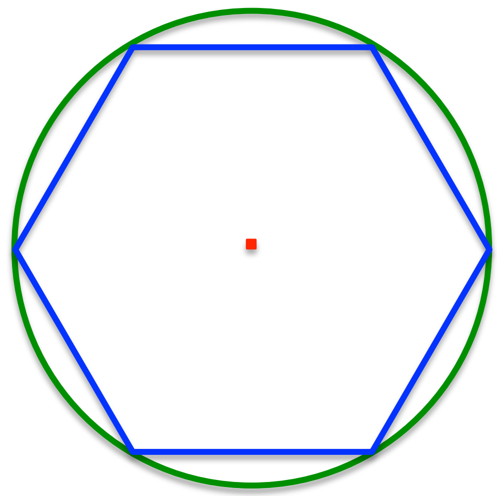
Coadded depth in filter r, with design value subtracted (27.5), r band, all proposals (no dithers). More positive numbers indicate fainter limiting magnitudes.

Slide from Lynne Jones (UW)

Fixed Telescope Pointings

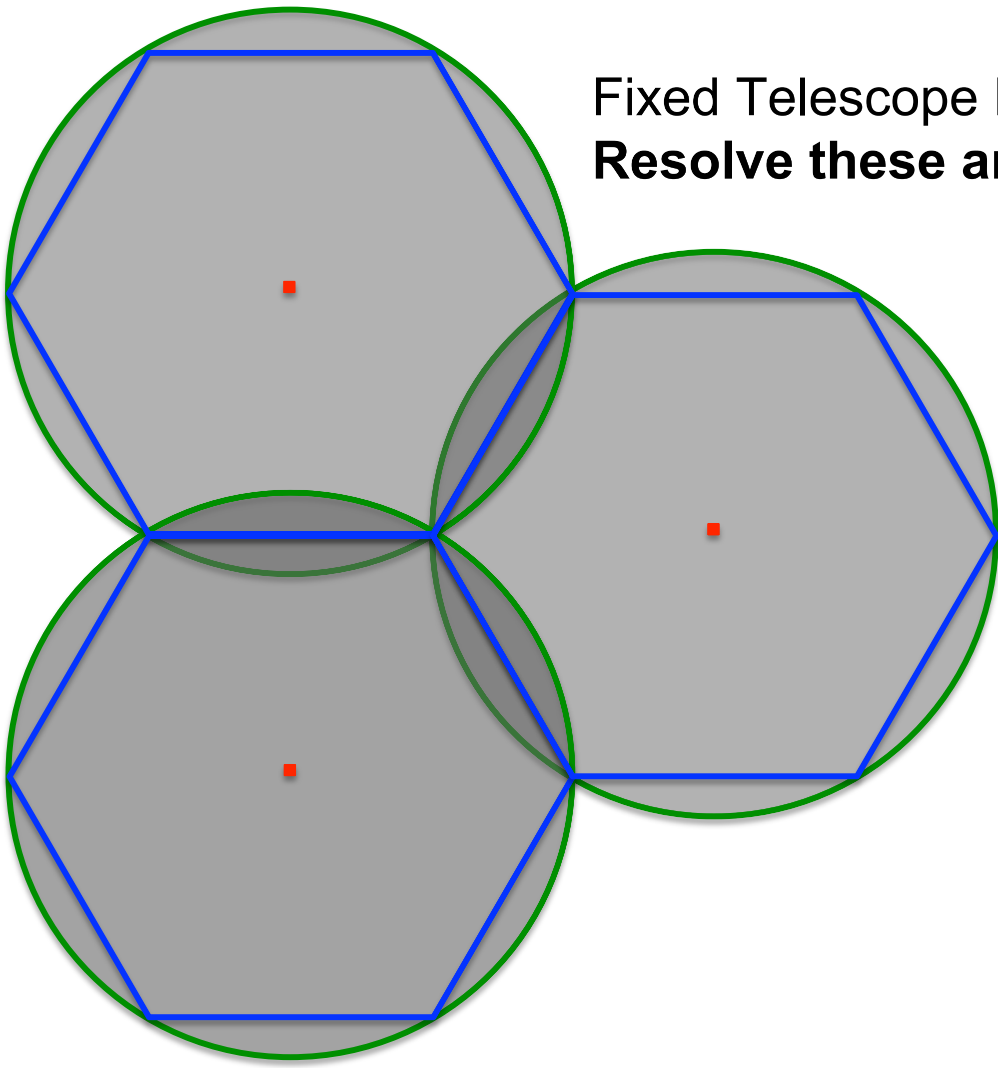
Tile the sky with hexagons inscribed in the circular LSST Field of View





Slide from Tony Tyson

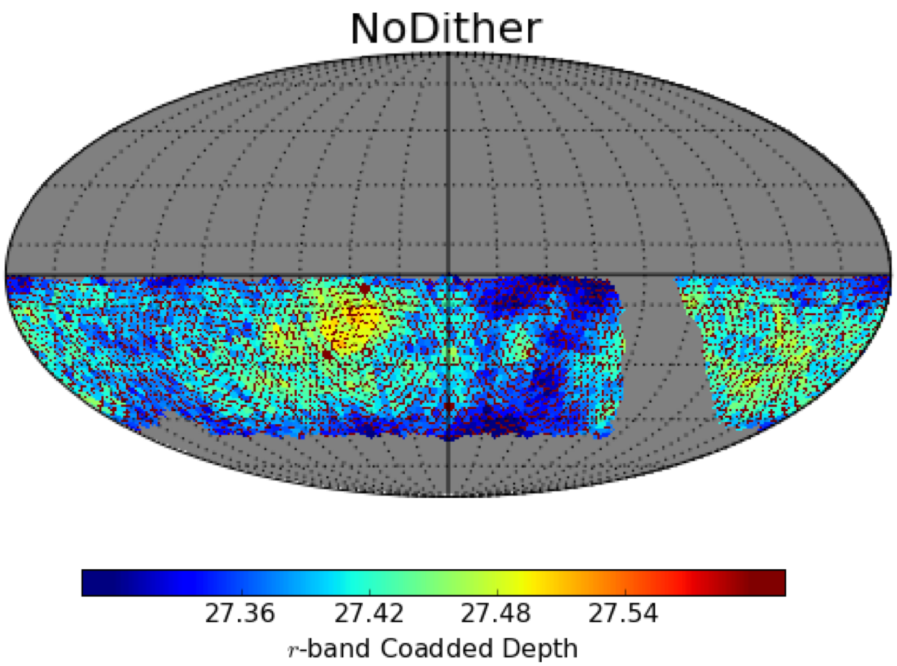
Fixed Telescope Pointings



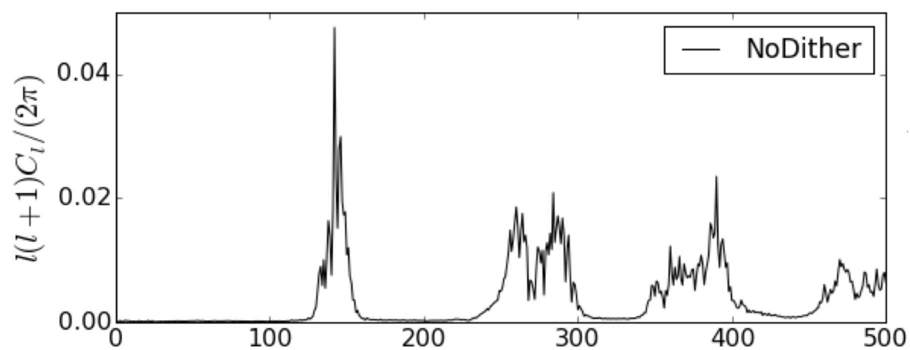
Fixed Telescope Pointings → overlapping regions

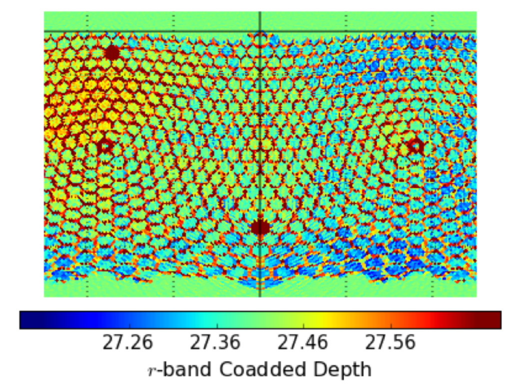
Resolve these angular scales to model impact

Fixed Telescope Pointings: Ten-Year Survey Depth



Power Spectrum





Zoom

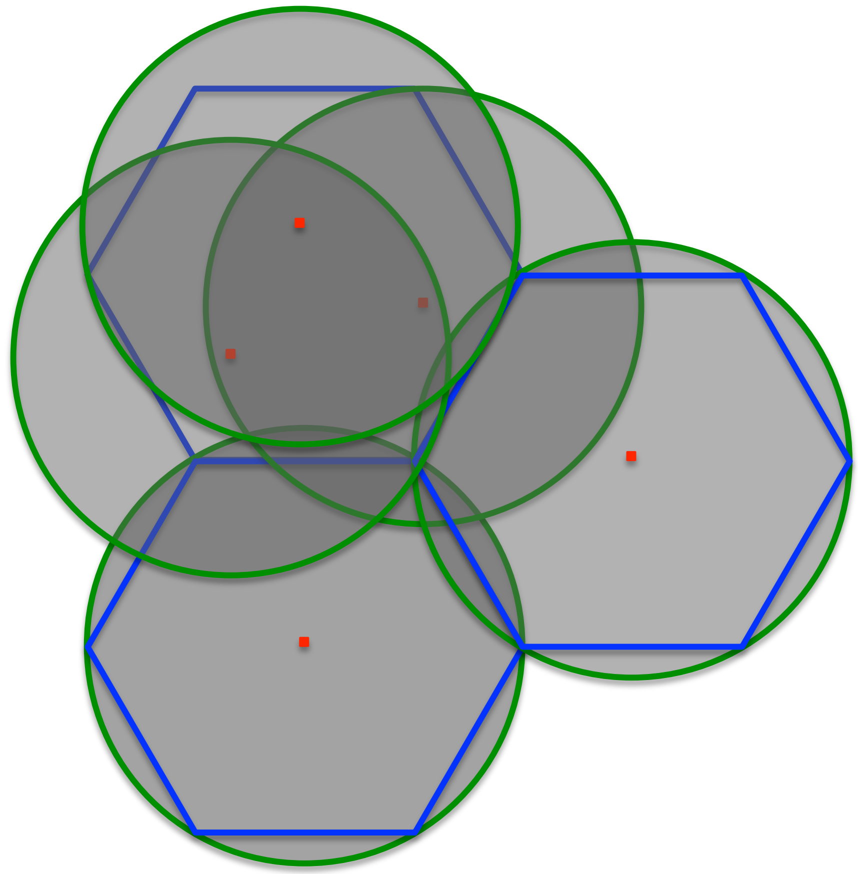
Honeycomb pattern: angular scale close to that of Baryon Acoustic Oscillation (BAO) signal. **NOT GOOD.**

Awan+16, arXiv:1605.00555

Dithering

Dithers:

- Telescope-pointing offsets within a single field-of-view

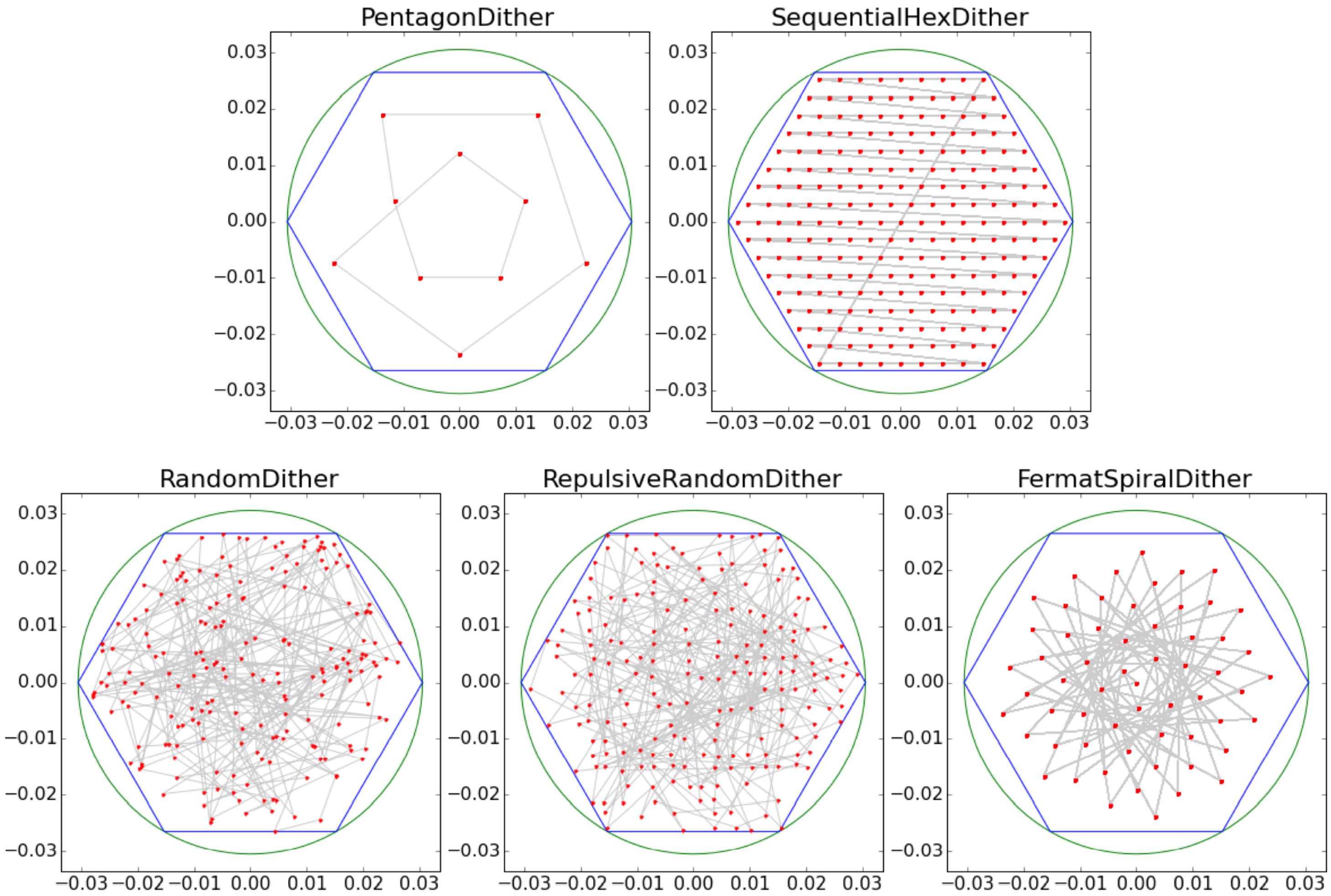


Advantages:

- Observation through many CCDs
- Reduce systematic errors from variations in sensitivity

Goal: explore different kinds of dithering strategies

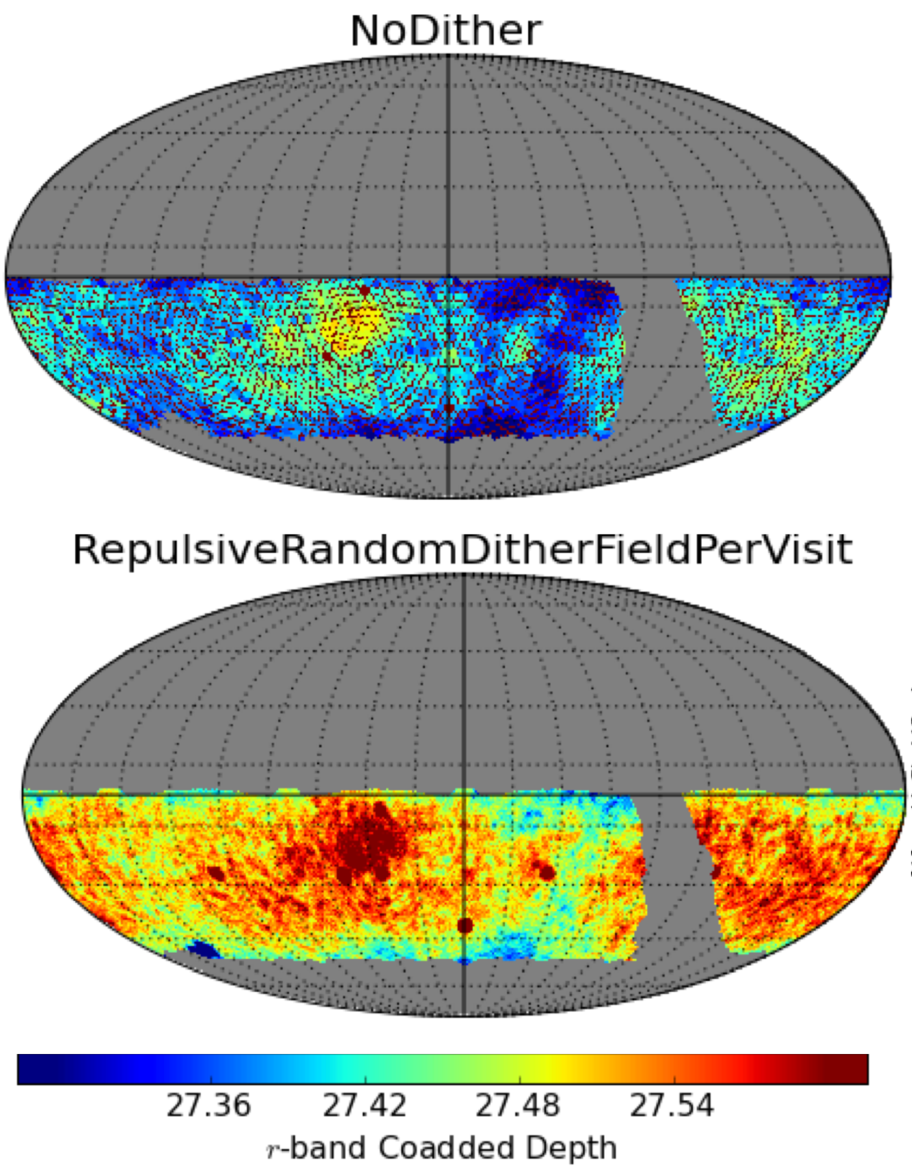
Dithering: Geometry & Timescale

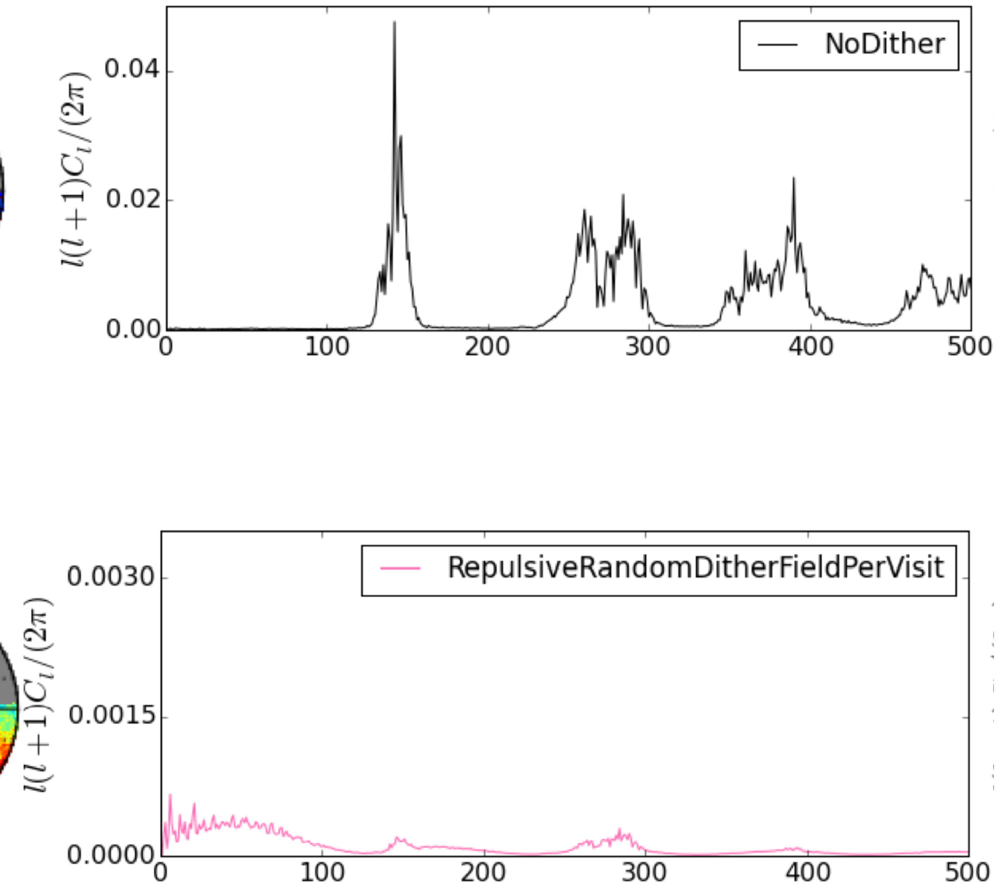


First is for dithering by season, rest are for nightly or per-visit dithers

Awan+16, arXiv:1605.00555

Ten Year Survey Depths





Angular Power Spectra

Awan+16, arXiv:1605.00555

What does this mean for LSS (BAO)?

- Estimate number of galaxies from the coadded depth
  - Mock LSST Lightcone catalogs (SAG) ➔ power law number counts for *z*-bins (Padilla, Munoz, Orsi et al)
  - Normalize to expected LSST counts (CFHTLS based)

- Find fluctuations in the galaxy counts: $\frac{N_{gal} - N_{average}}{N_{average}}$

Realistic Calculation of Galaxy Counts

- Calibration errors
- Dust extinction
- Magnitude Cuts

Awan+16, arXiv:1605.00555

Where's the Cross-Correlation?

Where's the Cross-Correlation?

$$\left(\frac{\mathrm{N_{gal}}}{\mathrm{N_{avg}}}\right)_{\mathrm{observed},i} = \left(\frac{\mathrm{N_{gal}}}{\mathrm{N_{avg}}}\right)_{\mathrm{OS},i} \left(\frac{\mathrm{N_{gal}}}{\mathrm{N_{avg}}}\right)_{\mathrm{LSS},i}$$

$$(1 + \delta_{\mathrm{observed},i}) = (1 + \delta_{\mathrm{OS},i})(1 + \delta_{\mathrm{LSS},i})$$

$$\delta_{\mathrm{observed},i} = \delta_{\mathrm{LSS},i} + \delta_{\mathrm{OS},i} + \delta_{\mathrm{LSS},i}\delta_{\mathrm{OS},i}$$

Equations from Awan+16, arXiv:1605.00555

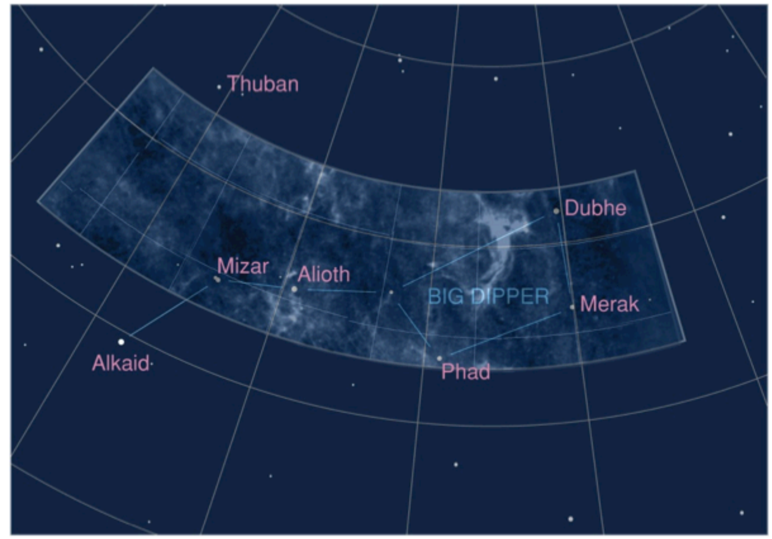
LSST Survey Design Results

Dark Energy probes limited by systematics that depend on survey design

Dithering strategies cause a bias in C_l measurements as well as uncertainty in that bias; the latter can be made sub-dominant with a sufficiently good dithering strategy

LSST with big dithers will be able to study LSS/BAO, but quality of Year 1 results depends greatly on choice of dither pattern
(Awan+16, arXiv:1605.00555)

The Hobby Eberly Telescope Dark Energy Experiment (HETDEX) is:



→ **blind spectroscopic survey on**

9.2m Hobby-Eberly Telescope

→ **400 square degrees in 140 nights**

over 3 years

→ **700,000 redshifts from 1.9<z<3.5**

(Ly-alpha emitters)

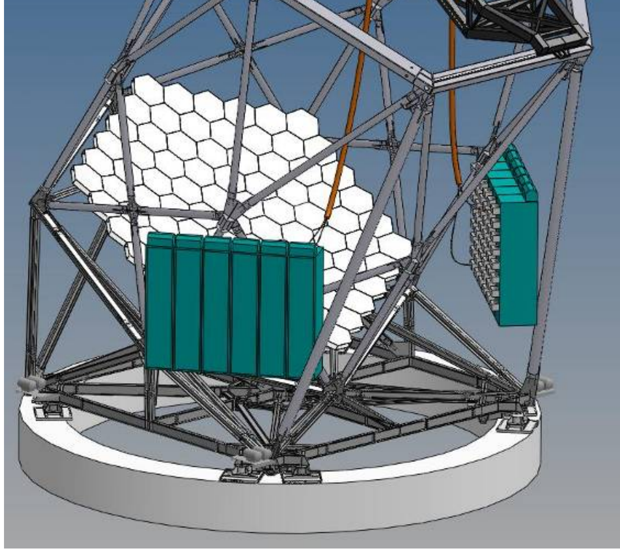
→ **upgraded telescope with new top-end, including 22' field of view**

→ **new instrument, VIRUS, with 150 "integral field" spectrographs (λ / $\Delta\lambda$ = 800 from 350 – 580nm)**

→ prototype **unit spectrograph has been in use since 2006**

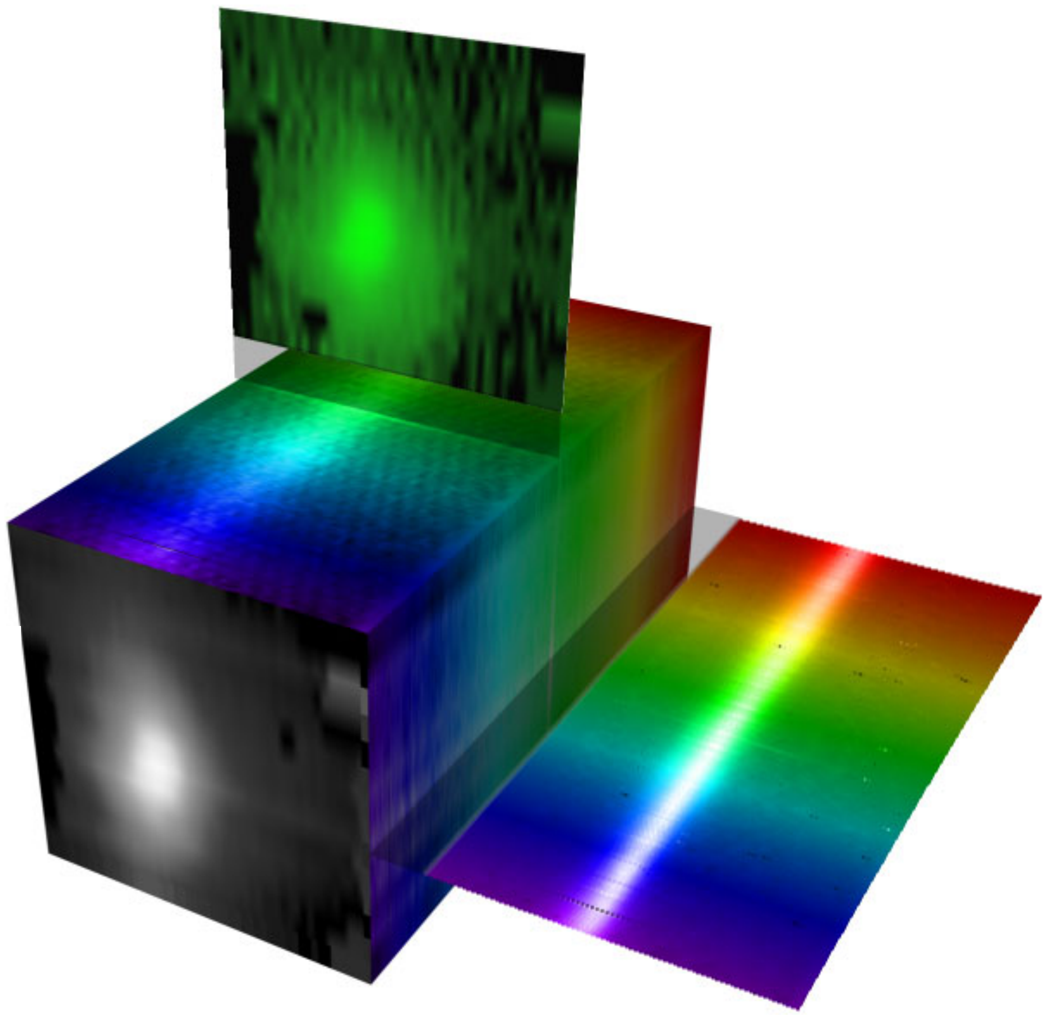
TIMELINE: 2016-2019 **PRICETAG:$45M**

PI Gary Hill, PS Karl Gebhardt (UT Austin)



HET is the world's fourth largest telescope. It will be upgraded with a powerful new instrument consisting of 150 units, VIRUS (Visible **I**ntegral-field **R**eplicable **U**nit **S**pectrograph)

INTEGRAL FIELD SPECTROSCOPY



The active galaxy NGC1068, imaged using an Integral Field Unit

Image: Stephen Todd, ROE and Douglas Pierce-Price, JAC.

HETDEX should provide:

→ **$H(z=2.5)$ to 1%**

→ **$D(z=2.5)$ to 1%**

→ **significant improvement on dark energy evolution (w_a)**

→ **curvature measure to about 10^{-3} (~5x better than present)**

→ **amplitude of power spectrum to 2% (structure growth)**

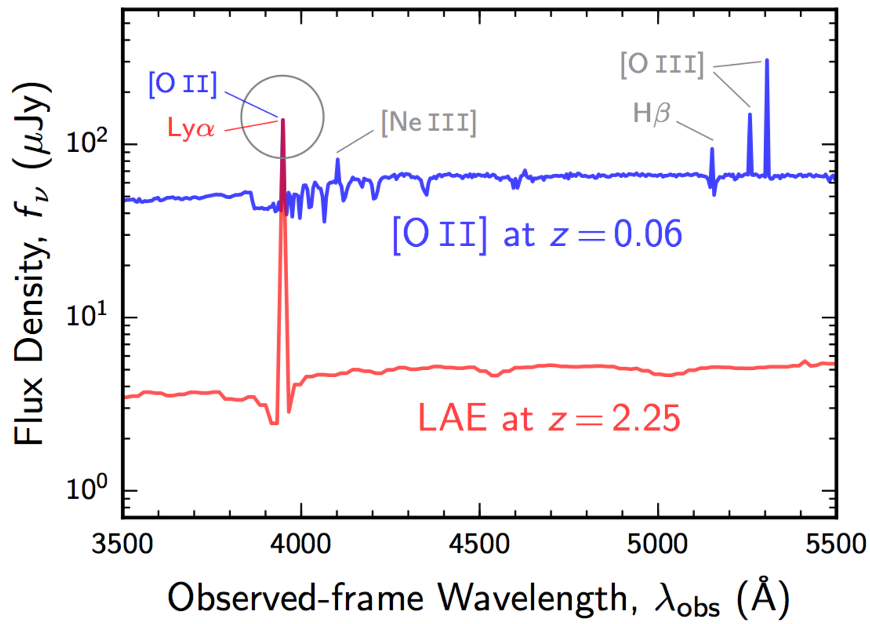
The Single Emission Line Challenge:

Separate ~1,000,000 emission-line detections into ~500,000 distant Lyα-Emitting (LAE) galaxies and ~500,000 nearby [O II]-emitting galaxies with <1% error rate

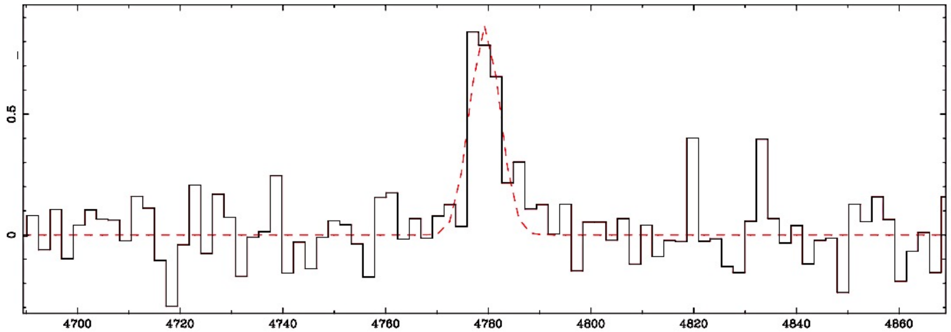
Precision on cosmological parameters depends on purity and completeness of LAE sample

Unique identification of Lyα (rest-frame 1216 Å) emission line problematic due to

- HETDEX spectral resolution: 5.7 Å
- contamination from unresolved [O II] doublet (rest-frame 3726, 3729 Å)



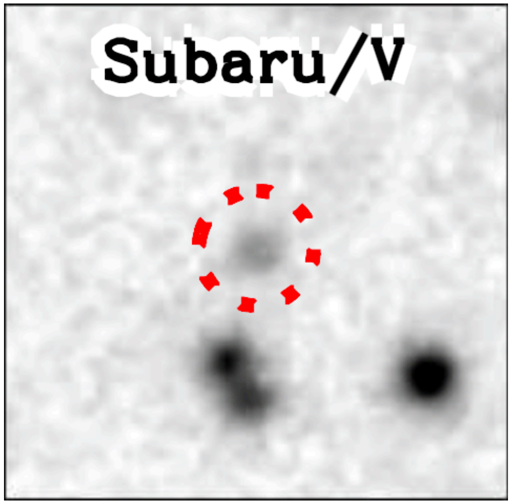
Photometric Equivalent Width Selection



Adams et al. (2011)

Traditionally: EW > 20 Å

emission line flux
[erg/s/cm^2]



Song et al. (2014)

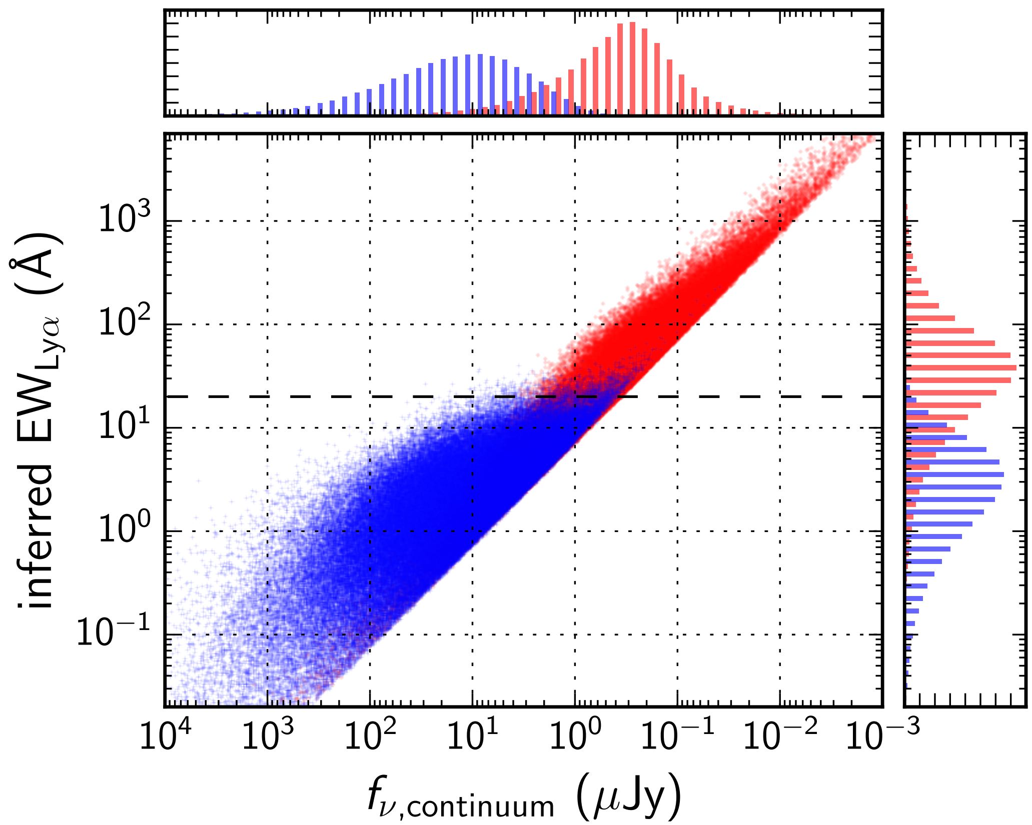
continuum flux density
[erg/s/cm^2/Å]

Observable Properties

Simulated line flux-limited emission line detections

- *y* axis: assume line is Lyα, determine rest-frame EW
- diagonal cutoff: HETDEX 5σ line detection limit

Simulated mock catalogs obey published luminosity functions and EW distributions for LAE & [O II] galaxies (Ciardullo+ 2012, 2013)



LAEs ($1.9 < z < 3.5$)

[O II] emitters ($z < 0.5$)

Bayesian Method

Bayes' theorem gives the *posterior* degree of belief in model A given data B:

$$P(\mathsf{A}|\mathsf{B}) = \frac{P(\mathsf{B}|\mathsf{A}) \cdot P(\mathsf{A})}{P(\mathsf{B})}$$

Given the observed characteristics of an emission-line object, i.e., wavelength, equivalent width, emission line flux

$\Longrightarrow$We can compute the relative likelihood that the galaxy in question is an LAE as a ratio of probabilities

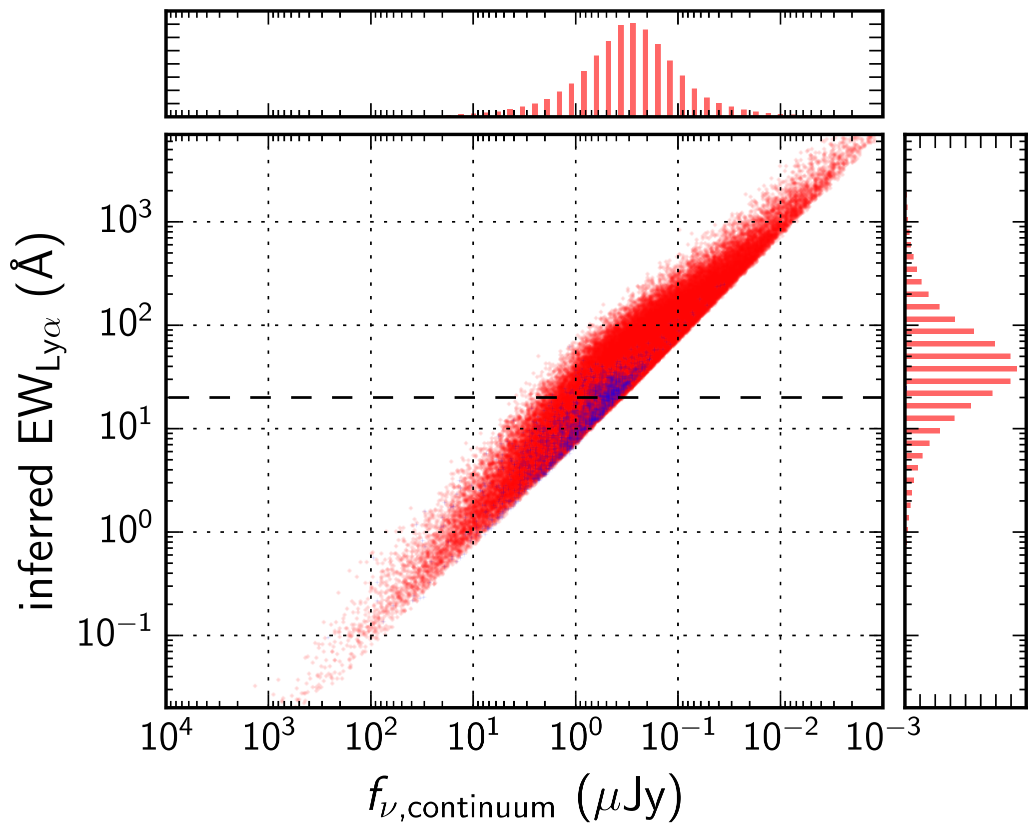
$$\frac{P(\mathsf{LAE}|\mathsf{data})}{P([\mathsf{O}\,\textsc{ii}]|\mathsf{data})} = \frac{P(\mathsf{data}|\mathsf{LAE})}{P(\mathsf{data}|[\mathsf{O}\,\textsc{ii}])} \frac{P(\mathsf{LAE})}{P([\mathsf{O}\,\textsc{ii}])}$$

Bayesian Method – LAE Sample

method	**Bayesian**	EW>20Å
fractional contamination	**0.91%**	0.94%
sample incompleteness	**7.7%**	31%

LAEs ($1.9 < z < 3.5$)

[O II] emitters ($z < 0.48$)



Leung+16, ArXiv:1510.07043

Where's the Cross-Correlation?

Reality check on EL classification:
cross-correlate LAE & [O II] samples of various confidence levels to measure contamination

$\xi_{12}(r)_{observed} = (1-f_{21})(1-f_{12})\, \xi_{12}(r) + f_{21}\, \xi_{11}(r) + f_{12}\, \xi_{22}(r)$

$\xi_{12}(r)_{observed} = f_{21}\xi_{11}(r) + f_{12}\xi_{22}(r)$ (for uncorrelated types)

Use this to correct $\xi_{11}(r)_{observed}$ & $\xi_{22}(r)_{observed}$ for contamination e.g.
$\xi_{11}(r)_{observed} = (1-f_{12})^2\, \xi_{11}(r) + f_{12}^{\ 2}\, \xi_{22}(r)$

(Over)Confident Statements Designed to Spur Discussion

- Bayesian method improves relative precision of cosmological distance measurements over traditional EW > 20 Å selection by ~20%
  (Leung+16, ArXiv:1510.07043)
- This approach can help Euclid, WFIRST, SPHEREx, and 21 cm surveys classify single emission lines

- LSST & HETDEX (etc.) will make great progress with astrophysical "Big Data" but need careful analyses including cross-correlations to handle corresponding "Big Systematics"